ERDC/CERL TR-04-18

Construction Engineering Research Laboratory

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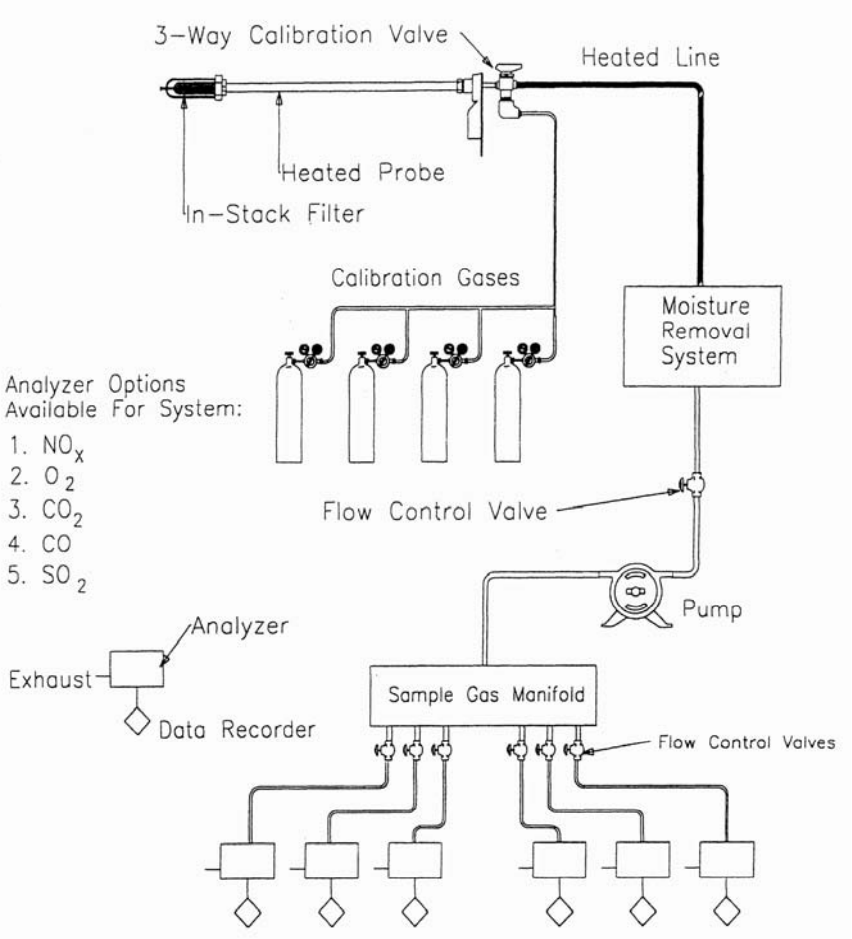
Results of Source Emissions Testing

UTC Fuel Cell Model PC25C

Melissa White and William R. Taylor

September 2004



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Results of Source Emissions Testing: UTC Fuel Cell Model PC25C

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Final Report

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ABSTRACT: Fuel cells generate electricity through an electrochemical process that combines hydrogen and oxygen to generate direct current (DC) electricity. Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93), and has overseen the purchase, installation, and ongoing monitoring of fuel cells in the "DOD Fuel Cell Demonstration Program." This report documents a source emission study done on fuel cells at Fort Huachuca, in Tempe, AZ. This report describes the testing methods used to measure source emissions from the PC25C system, the conditions during the process, and the test results. Results are tabulated with the manufacturer's emissions ratings.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
Feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
Inches	0.0254	meters
inches of water (60 °F)	2.4884×10^2	pascal
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

*_Système International d'Unités_ ("International System of Measurement"), commonly known as the "metric system."

Preface

In fiscal years 93 and 94, Congress provided funds for natural gas utilization equipment, part of which was specifically designated for procurement of natural gas fuel cells for power generation at military installations. The purchase, installation, and ongoing monitoring of 30 fuel cells provided by these appropriations has come to be known as the "DOD Fuel Cell Demonstration Program." Additional funding was provided by: the Office of the Deputy Under Secretary of Defense for Industrial Affairs & Installations, ODUSD (IA&I)/HE&E; the Strategic Environmental Research & Development Program (SERDP); the Assistant Chief of Staff for Installation Management (ACSIM); the U.S. Army Center for Public Works (CPW); the Naval Facilities Engineering Service Center (NFESC); and Headquarters (HQ), Air Force Civil Engineer Support Agency (AFCESA).

The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was William Taylor. The source emissions study was performed by Applied Environmental Consultants, Inc., Tempe, AZ. The technical editor was William J. Wolfe, Information Technology Laboratory. Dr. Thomas Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche, CEERD-CV-T. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Fuel cells generate electricity through an electrochemical process that combines hydrogen and oxygen to generate direct current (DC) electricity. Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. Air emissions from fuel cells are so low that several Air Quality Management Districts in the United States have exempted fuel cells from requiring operating permits. Today's natural gas-fueled fuel cell power plants operate at electrical conversion efficiencies of 40 to 50 percent; these efficiencies are predicted to climb to 50 to 60 percent in the near future. In fact, if the heat from the fuel cell process is used in a cogeneration system, efficiencies can exceed 85 percent. By comparison, current conventional coal-based technologies operate at efficiencies of 33 to 35 percent.

Fuel cell technology has been found suitable for a growing number of applications. The National Aeronautics and Space Administration (NASA) has used fuel cells for many years as the primary power source for space missions and currently uses fuel cells in the Space Shuttle program. Private corporations have recently been working on various approaches for developing fuel cells for stationary applications in the utility, industrial, and commercial markets. Researchers at the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) have actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93), and have successfully executed several research and demonstration work units with a total funding of approximately $55M.

This report documents a source emission study done at Fort Huachuca, in Tempe, AZ. The fuel cells at this site are fueled with natural gas; the principal byproducts are heat, water, and low concentration combustion gases. The fuel cells studied at this site were United Technologies Corporation (UTC) Model No. PC25C. At the time of this study, the PC25C was the world's only commercially available fuel cell system with a rated capacity of 200 kilowatts. The fuel cells under study are used to power a military personnel barracks.

Objective

The overall objective of this project was to demonstrate and study fuel cells in use at military or Federal government facilities. The specific objective of this work was to study fuel cell source emissions at one project site—Fort Huachuca, Tempe, AZ.

Approach

1. EPA Test Methods were used for each emission unit and emission species.
2. Data was recorded at 60-second intervals.
3. Fuel cells were tested at three different power output levels: 100, 150, and 170 kilowatts.
4. Results were recorded, analyzed, and compared with the manufacturer's listed values.

Mode of Technology Transfer

The results of this work will be provided to installation personnel at the host site, and will be used to further the ongoing monitoring of fuel cells in the "DOD Fuel Cell Demonstration Program."

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 Test Methods

Equipment

A custom sheet metal duct was fabricated and placed on top of the fuel cell's exhaust stack to serve as the sample port. Table1 lists the gaseous analyzers used in the test program. Stack gas was extracted through a stainless steel in-stack probe, heated Teflon® tubing, and an on-stack condenser that cooled and dried the gas sample. Conditioned sample gas then passes through Teflon® tubing to the gas manifold where it was distributed to the instrument analyzers. Excess stack gas was vented to the outside air. Zero gas and span gases were introduced directly into each analyzer via the probe tip for bias checks. The gas manifold is constructed of Teflon® tubing and stainless steel solenoids and fittings. Figure 1 schematically shows a multi-component gaseous sampling train.

The EPA Test Methods used for each emission unit and emission species are:

- Flow rates were measured using EPA Methods 1 and 2.
- Moisture was measured using Method 4.
- O_2/ CO_2 was measured using method 3A.
- NO_x was measured using method 7E.
- CO was measured using method 10.
- SO_2 was measured using method 6C.
- VOC was measured using methods 25A and 18.

Table 1. Monitoring equipment description.

Parameter	Analyzer Manufacturer	Instrument Model	Operating Principle
CO	TECO	Model 48C	Gas Filter Correlation/Infrared
NOx	TECO	Model 42C	Chemiluminescence
SO_2	AMETEK	Model 921	Ultraviolet Photometric
THC	J.U.M. Engineering	Model 300A	Flame Ionization Detector
CO_2	California Analytical	Model ZRH	Non-Dispersive Infrared
O_2	Siemens	Model Oxymat 6E	Paramagnetic

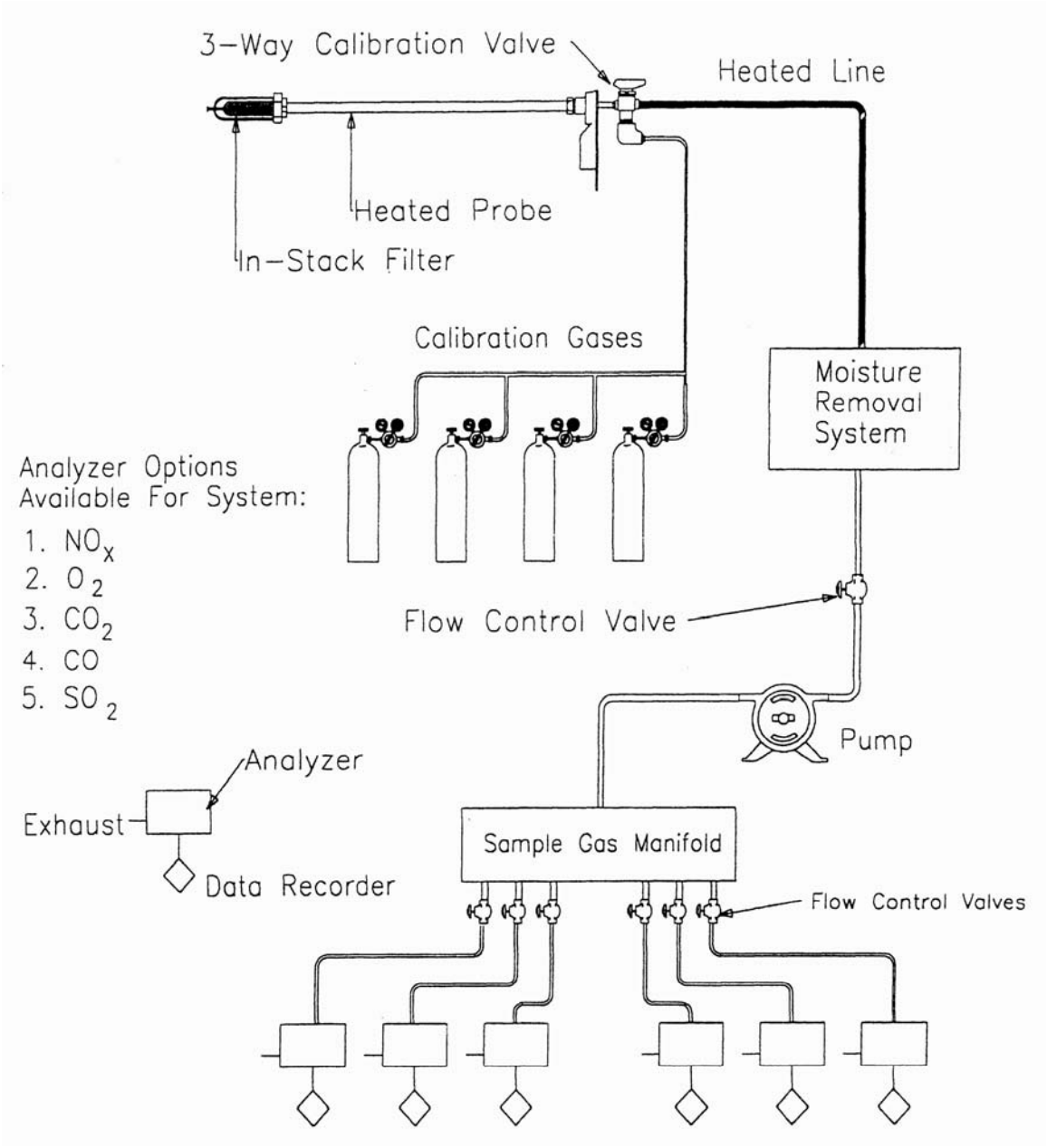

Figure 1. Multi-component gaseous sample train.

Description of Test Methods

Data recording was done with the aid of an ESC Model 8816 data logger. Each instrument output was recorded continuously and the collected data was averaged and stored into the data logger every 60 seconds. Data retrieval into an IBM compatible computer was done through the RS232 communication port with

the aid of AEC's proprietary software, which is capable of recording the data directly into a Microsoft® Excel® spreadsheet on a minute-by-minute basis.

The following is a brief summary of each of the applicable test methods used during the testing program:

- ***EPA Method 1: Sampling and Velocity Traverses for Stationary Sources***

  Before the source test, a site assessment was performed to locate sample points for obtaining the best representative measurements of pollution concentrations and volumetric flow rates. EPA Method 1 takes into account duct area, straight run, and cyclonic or stratified flow patterns.

- ***EPA Method 2: Determination of Velocity and Volumetric Flow Rates***

  The velocity of the gas stream was determined by using a "Standard" type pitot tube, an inclined manometer, and type "K" thermocouple probe with a digital temperature-measuring device. The pitot tube was connected to the inclined manometer and leak checked. Temperature and ΔP readings were obtained at each traverse point. A duct static pressure was also measured and recorded. The dry volumetric flow rate was determined from the gas velocity data, stack pressure, stack gas moisture content, stack gas molecular weight, and cross-sectional area of duct.

- ***EPA Method 3A: Determination of CO_2 and O_2 by Instrumental Analyzer***

  A gas sample was continuously extracted from the stack through a stainless steel sample probe into a condenser to cool and dry the sample, through Teflon® sample line, and continuous O_2 and CO_2 analyzers (Siemens Model Oxymat-6E and Fuji Model ZRH). Continuous O_2 and CO_2 measurements in percent were recorded on a data acquisition system. The O_2 and CO_2 analyzers were calibrated before sampling using zero, mid-range, and high-range EPA protocol gases. Following each test run, a sampling system bias check was performed by introducing zero and upscale (either mid-range or high-range) EPA Protocol gas into the sampling system at the back end of the sample probe.

- ***EPA Method 4: Determination of Stack Gas Moisture Content***

  Moisture content was determined with the Method 4 sampling system. Before sampling, a leak check of the sampling train was performed to ensure system integrity. Tare weights of the charged individual impingers were recorded before the start of the sampling run using a top loading digital balance capable of weighing to the nearest 0.1 gram or less. After sampling, the final weight of each impinger was determined and recorded. Percent moisture content was calculated from the weight of water collected and the dry gas volume sampled.

- ***EPA Method 6C: Determination of Sulfur Dioxide Emissions***

  A gas sample was continuously extracted from the stack through a stainless steel sample probe into a condenser to cool and dry the sample, through Teflon® sample line, and into an UV photometric absorption SO_2 analyzer. Continuous SO_2 measurements are recorded on a strip chart recorder and data acquisition system. The SO_2 analyzer was calibrated before sampling using zero, mid-range, and high-range EPA Protocol gases. Following the test runs a sampling system bias check was performed by introducing zero and upscale (either mid-range or high-range) EPA Protocol gas into the sampling system at the back end of the sam-

pling probe. Before and following each run, a zero and calibration check was performed by introducing zero and upscale (either mid-range or high-range) EPA Protocol gas into the analyzer.

- ***EPA Method 7E: Determination of Nitrogen Oxides Emissions***

  A gas sample was continuously extracted from the stack through a stainless steel sample probe into a condenser to cool and dry the sample, through a heated Teflon sample line, and into a chemiluminescent NO_x analyzer (TECO Model 42C). Continuous NO_x measurements in ppm were recorded on a data acquisition system. The NO_x analyzer was calibrated before sampling using zero, mid-range, and high-range EPA Protocol gases. Before each test run, a sampling system bias check was performed by introducing zero and upscale (either mid-range or high-range) EPA Protocol gas into the sampling system at the back end of the sample probe. Stack gas NO_x concentrations were corrected for the sampling system zero and upscale drift in accordance with EPA Method 7E.

- ***EPA Method 10: Determination of Carbon Monoxide Emissions***

  A gas sample was continuously extracted from the stack through a stainless steel sample probe into a condenser to cool and dry the sample, through heated Teflon sample line, and into a gas filter correlation CO analyzer (TECO Model 48C). Continuous CO measurements in ppm were recorded on a data acquisition system. The CO analyzer was calibrated Before sampling using zero, mid-range, and high-range EPA Protocol gases. Before each test run, a sampling system bias check was performed by introducing zero and upscale (either mid-grade or high grade) EPA Protocol gas into the sampling system at the back end of the sample probe. Stack gas CO concentrations were corrected for the sampling system zero and upscale drift in accordance with EPA Method 10.

- ***EPA Method 18: Determination of Gaseous Organic Compound Emissions***

  Stack gas was extracted from the stack through a stainless steel sample probe and/or a Teflon sample line into an evacuated Tedlar bag. Samples were analyzed for speciated hydrocarbons using gas chromatography within 72 hours of sampling.

- ***EPA Method 26A: Determination of Total Hydrocarbons***

  A gas sample was continuously extracted from the stack through a stainless steel sample probe, heated Teflon sample line (≥ 250 °F), and into a heated flame ionization detection THC (Total Hydrocarbons) analyzer. Continuous THC measurements were recorded on a data acquisition system. The THC analyzer was calibrated Before sampling using zero, low-range, mid-range, and high-range EPA Protocol gases what were introduced into the sample line at the probe tip. Before and following each run, a zero and span check was performed by introducing zero gas and EPA Protocol calibration gas into the analyzer through the probe tip. System response time was determined Before testing as described in Section 6.5 of EPA Method 25A.

The velocity traverse point locations for all emissions tests were determined following EPA Method 1 guidelines. A total of 12 traverse points were established by dividing the stack cross-section into equal rectangular elemental areas and then locating the point at the centroid of each area.

Process Conditions

The fuel cell was tested at three different power output levels: 100, 150, and 170 kilowatts. At the time of testing, 170 kW was the maximum output level at which the fuel cell could operate.

The rated capacity for the UTC Fuel Cell Model PC25C was 200 kW (or 235 kVA). The predicted fuel consumption level was recorded as 2050 cu ft/hr of natural gas, with the fuel cell operating between 4 and 14 in. of water pressure, with a combined electrical and thermal efficiency of 87 percent.

3 Test Results

Two sets of tests were performed. Table 2 lists data from the first (2 August 2002) test; Table 3 lists data from the second (4-5 November 2002) test; Table 4 lists test averages, the manufacturer's "standard" specifications for the product, and the manufacturer's test values,* which served as the basis for the more conservative manufacturer's published standard. The CO reading of 1.0 ppm during the 150 kW test (Table 2) led to a review of the test setup and calibration samples, but no discrepancies were found to explain the atypical reading. The NOx readings show little variance between power level tests and between the two tests. SOx emissions, barely detectable in the first test, were slightly higher in the second test. VOCs were higher in the first test and increased at higher power levels. All average readings for NOx, CO, and SOx were at or below the manufacturer's test values (Table 4). VOC readings were higher than the manufacturer's test values, but still below manufacturer's published standard.

Table 2. Test at Fort Huachuca, 2 Aug 2002 (15% O_2, Dry).

Test	Parameters	Test Averages	Run 2 (100 kW)	Run 1 (150 kW)	Run 3 (170 kW)
Stack Gas Parameters	Carbon Dioxide (%)		5.50%	6.06%	7.77%
	Volumetric Flow Rate (dscfm)		303	427	431
	Firing Rate (MMBtu/hr)*		0.94	1.56	1.83
NOx - Oxides of Nitrogen	Ppm	0.24	0.26	0.24	0.22
	lb/MMBtu	0.00031	0.00039	0.00029	0.00024
(EPA Method 7E)	lb/hr	0.00042	0.00037	0.00046	0.00044
CO - Carbon Monoxide	Ppm	0.34	0.02	1.00	0.01
	lb/MMBtu	0.00043	0.00003	0.00125	0.00001
(EPA Method 10)	lb/hr	0.00066	0.00003	0.00194	0.00002
SOx - Sulfur Dioxide	ppm	0.00	0.001	0.000	0.000
	lb/MMBtu	0.00000	0.00000	0.00000	0.00000
(EPA Method 6C)	lb/hr	0.00000	0.00000	0.00000	0.00000
VOCs - Volatile Organic Compounds	ppm	1.00	0.65	0.90	1.45
	lb/MMBtu	0.0012	0.0010	0.0011	0.0016
(EPA Method 25A/18) as C_1**	lb/hr	0.0018	0.0009	0.0018	0.0029

* Manufacturer's test values are unpublished data obtained informally from the manufacturer; they represent the manufacturer's in-house uncorroborated testing of several units and are provided for informational purposes only.

Table 3. Test at Fort Huachuca, 4-5 Nov 2002 (15% O_2, Dry).

Test	Parameters	Test Averages	Run 2 (100 kW)	Run 1 (150 kW)	Run 3 (170 kW)
Stack Gas Parameters	Carbon Dioxide (%)		5.50%	6.06%	7.77%
	Volumetric Flow Rate (dscfm)		303	427	431
	Firing Rate (MMBtu/hr)*		0.94	1.56	1.83
NOx - Oxides of Nitrogen (EPA Method 7E)	ppm	0.28	0.32	0.28	0.24
	lb/MMBtu	0.00036	0.00047	0.00034	0.00026
	lb/hr	0.00049	0.00044	0.00054	0.00048
CO - Carbon Monoxide (EPA Method 10)	ppm	0.01	0.01	0.01	0.01
	lb/MMBtu	0.00001	0.00001	0.00001	0.00001
	lb/hr	0.00001	0.00001	0.00001	0.00001
SOx - Sulfur Dioxide (EPA Method 6C)	ppm	0.04	0.06	0.03	0.05
	lb/MMBtu	0.00006	0.00009	0.00003	0.00005
	lb/hr	0.00007	0.00008	0.00005	0.00009
VOCs - Volatile Organic Compounds (EPA Method 25A/18) as C_1	ppm	0.14	0.14	0.14	0.14
	lb/MMBtu	0.00018	0.00021	0.00018	0.00015
	lb/hr	0.00025	0.00020	0.00028	0.00028

Table 4. Comparison of Fort Huachuca and Manufacturer Data (15% O_2, Dry).

Stack Gas Parameters	Parameters	100 kW Test Averages	150 kW Test Averages	170 kW Test Averages	Manufacturer's Test Values	Manufacturer's Standard
NOx (Oxides of Nitrogen) EPA Method 7E	ppm	0.29	0.26	0.23	0.46	1.00
	lb/MMBtu	0.00043	0.00032	0.00025	0.00170	
	lb/hr	0.00040	0.00050	0.00046	0.00319	
CO (Carbon Monoxide) EPA Method 10	ppm	0.01	0.50	0.01	1.10	5.00
	lb/MMBtu	0.00002	0.00063	0.00001	0.00240	
	lb/hr	0.00002	0.00098	0.00001	0.00464	
SOx (Sulfur Dioxide) EPA Method 6C	ppm	0.03	0.01	0.02	Not tested	Negligible
	lb/MMBtu	0.00004	0.00002	0.00002		
	lb/hr	0.00004	0.00003	0.00004		
VOCs (Volatile Organic Compounds) (EPA Method 25A/18) as C_1	ppm	0.39	0.52	0.79	0.03 *	1.00
	lb/MMBtu	0.00058	0.00065	0.00086		
	lb/hr	0.00055	0.00102	0.00158		
*Non-methane hydrocarbons						

4 Conclusion

The results of the tests performed on the PC25C fuel cell system at Fort Huachuca showed emissions at or below manufacturer's published specifications for the PC25C. The low emissions ratings of fuel cells s corroborated in these tests indicate that fuel cells represent a potential means to effect significant environmental improvements in energy technology.

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14. ABSTRACT

Fuel cells generate electricity through an electrochemical process that combines hydrogen and oxygen to generate direct current (DC) electricity. Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93), and has overseen the purchase, installation, and ongoing monitoring of fuel cells in the "DOD Fuel Cell Demonstration Program." This report documents a source emission study done on fuel cells at Fort Huachuca, in Tempe, AZ. The testing methods used to measure source emissions from the PC25C system, the conditions during the process, and the results of the test are described. Results are tabulated with the manufacturer's emissions ratings.

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